EFFECTS OF SOIL ARTHROPODS AND EARTHWORMS ON THE GROWTH OF BLACK SPRUCE

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INTRODUCTION

The activities of soil animals bring about changes in soil that are expected to influence plant growth. Apart from certain pest species, particularly in the *Mollusca*, *Nematoda* and *Insecta*, the majority of soil animals are saprophagous or obtain their food from fauna and flora that feed directly on dead organic matter. Several benefits have been recognized from this complex feeding inter-relationship. The fauna serves as a reservoir of nutrients that become available to plants when the animals die (METZ and FARRIER, 1965). Arthropods, by their fragmentation and translocation of organic matter and their dispersal of spores, stimulate microbial growth and enhance mineralization (BOCOCK, 1964 ; WITKAMP and CROSSLEY, 1966 ; KEVAN, 1968 ; MACFAYDEN, 1968). In addition to the comminution of organic matter, earthworms are credited with influencing soil fertility in many other ways. Their burrows permit the penetration of air and water into the soil and their casts contain a high proportion of clay-humus complexes that provide greater crumb stability and increase water retention (BARLEY, 1961 ; GERARD, 1963). They neutralize soil (LANGMAID, 1964) and increase the availability of nitrogen, phosphorus, potassium, calcium, magnesium and other essential elements for plant growth (ROOTS, 1956 ; SATCHELL, 1958, 1967 ; RODALE, 1961).

The effects of fauna on the soil have received much attention, but how these are reflected in plant growth is not well understood. Information is available on lumbricid activities on pasture productivity in DUFF (1958), SATCHELL (1958), BARLEY (1961), RODALE (1961), BACHELIER (1963) and RHEE (1969) ; on field crops in SATCHELL (1958), RHEE (1965) and ATLAVINYTÉ *et al.* (1968) ; and on yields in orchards in BARRETT (1949). Forest trees, however, have been neglected.

The present paper describes the influences of arthropods and earthworms on the

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growth of black spruce (*Picea mariana* (MILL.) BSP) in a greenhouse experiment ; the effects of the fauna on the release of available nutrients from the soil ; and changes in the soil faunal populations. This is a preliminary study to more extensive field investigations on the effects of soil animals on forest tree growth.

MATERIALS AND METHODS

Growth Medium

Soil samples were collected from a coniferous stand at the Petawawa Forest Experiment Station, Chalk River, Ontario, Canada. The location has been described in detail by FRASER (1958) and supports mainly black spruce on a podzolic soil derived from loamy sand of an old ground moraine. The samples were from a poorly drained area with a mor-type humus form : L (2.1-cm thick), F (1.7-cm thick), H (2.4-cm thick), A_2 (2.5-cm thick) ; B (20-cm thick). The pH value for the top 15 cm of the profile was 5.1. Fifteen-centimetre clay pots were filled with undisturbed 15-cm deep monolith samples, containing the organic layers and A and B horizons of the mineral soil. Larger 26-cm diameter pots were employed after nine months, when the plants were becoming root-bound, with an increase weight in soil from 1.1 to 3.8 kilograms.

Seedlings of uniform shape 10-cm high were selected from a seven-month old stock and planted one per pot in October 1968. They were placed on greenhouse benches, at 21-24°C under 20-hour artificial light (10,000 lux at the surface of the soil) for seven months and then in natural sun light. Height measurements were taken at monthly intervals until the study was terminated after 12 months, at which time root collar measurement were made with metric calipers. Seedlings were removed from soil, separated into roots, stems, branches and needles for oven dry weight (at 80°C). Soil pH measurements of a soil-water paste were made with a Beckman Model G instrument employing a glass electrode (*cf.* BLACK, 1965).

Faunal Treatments

The experiment was completely randomized with 20 replications of one pot each with four different soil faunal treatments for a total of 80 pots. Treatment (A) was untreated field soil that served as the control ; (B) contained its natural fauna plus two species of earthworms : two specimens of *Lumbricus terrestris* L. and four specimens of *Allolobophora caliginosa* (SAVIGNY) per pot and at the average rate of 9.0 g/kg of soil, which is within field limits. These pots were covered with 7-cm mesh nylon screen to prevent the worms from escaping. The worms were collected by the formalin technique (RAW, 1959) from a loamy sand supporting mixed hardwoods. Treatment (C) contained its natural animal populations plus dead earthworms at the rate of 8.8 g/kg of soil ; and (D) was defaunated by air drying until animals ceased to emerge. At the end of the experiment, arthropods were extracted from composite litter samples of each treatment using the high-gradient apparatus described by MARSHALL (in press) and earthworms by hand sorting.

Foliar and Soil Analyses

These were carried out by the Pulp and Paper Research Institute of Canada. Before plants were removed from the soil, samples were collected in October for foliar analysis. A composite sample of each treatment, taken from the leader and first whorl of laterals of each plant, was determined as follows : N by semi-micro-Kjeldahl method (BLACK *et al.*, 1965) ; P colorimetrically by the ammonium molybdate method after wet oxidation with nitric and perchloric acids (ATKINSON *et al.*, 1958) ; and K, Ca and Mg by atomic absorption (DAVID, 1960). Soil samples from the top 15 cm of each pot were also bulked by treatment. These were then divided into three subsamples for analysis. Available N was determined by extraction with potassium chloride solution, and titrated with sulfuric acid after distillation in boric acid (BLACK *et al.*, 1965) ; P, K, Ca and Mg by similar methods as those for foliar analysis.

RESULTS

Growth Response

There was much variation in the growth of the plants. Table 1 gives the means of various aspects of yield that were measured. Stem weight for the live earthworm treatment was only significant at the 10 p. 100 level of probability as measured by the « F » test, but there were not sufficient consistent differences between other treatment means to show statistical significance. However, certain trends were interesting. Defaunated soil (D) produced the highest weight of dry matter. Top weight and root collar diameter for pots inoculated with live worms (B) were 17 p. 100 and 24 p. 100, respectively, higher than the control (A) ; stem weight for pots with live worms was 43 p. 100 higher than the control and over 16 p. 100 higher than the dead earthworm treatment (C) or defaunated soil (D). Top weight in the defaunated soil was 7 p. 100 higher than the controls.

TABLE I

Effects of different soil faunal treatments on the growth of 19-month-old black spruce. Oven dry weight of tops and roots

Treatment symbol †	Needle weight	Branch weight	Stem weight	Total top weight	Root weight	Total plant weight	Top root ratio	Stem height (cm)	Root collar (mm)
	gm/seedling								
A	9.4	3.5	7.2	20.1	15.8	35.9	1.3	63.1	8.0
B	9.2	4.1	10.3 *	23.6	15.4	39.0	1.5	64.8	9.9
C	9.4	3.7	8.8	21.9	16.2	38.1	1.5	65.9	8.7
D	9.1	3.6	8.9	21.6	17.7	39.3	1.2	64.4	8.7

† A, control ; B, live earthworms ; C, dead earthworms ; D, defaunated soil.
* Significant at the 10 p. 100 level of probability.

The developmental pattern of the plants for control and dead earthworm treatments were similar and intermediate between the other two treatments (fig. 1). Roots from the live earthworm treatment were short and matted, whereas those from plants growing in the defaunated soil were longer and less compact. The latter also exceeded all other treatments by more than 9 p. 100 dry weight. The live earthworm treatment, therefore, increased top-root ratio by suppressing root growth and increasing stem and branch productivity. Needle weights were very similar for all treatments and this was also reflected in the quantities of nutrients they contained (table. 2).

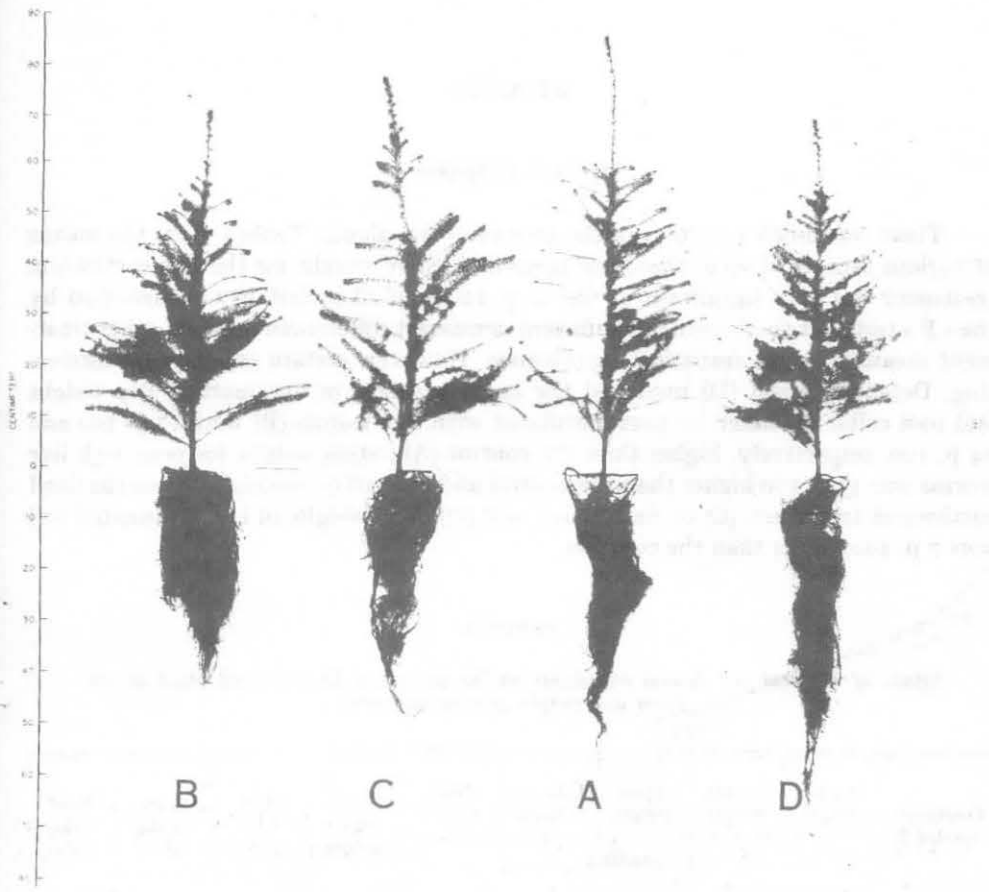

FIG. 1. — *Effects of different soil faunal treatments on 19-months-old black spruce seedlings*

A. Control
B. live worms
C. dead worms
D. defaunated

Soil Nutrients and pH

Table 2 also shows available macronutrients from the different treatments. The better stem growth in the live earthworm treatment (B, table 1) was evidently related to increased availability of nitrogen. The defaunated soil contained only 24 to 46 p. 100 as much exchangeable nitrogen as did the soils with animals. Readily-soluble phosphorus also appeared to be present in greater amounts in the live-earthworm treated soil but was not proportionately absorbed by the needles. Stem and root analysis, however, might have revealed it in high concentrations in these organs. Results for potassium, calcium and magnesium showed no clear trends and the high value of soil potassium in treatment C is difficult to explain.

In all cases the pH dropped from the original field value (5.1). The greatest reduction was in the soil with live earthworms. Pots were watered from above and

allowed to drain freely. The low concentration of potassium in treatment B suggests excess leaching of this element, resulting from better drainage brought about by worm activity. Acids created during the complex processes of decomposition, accompanying mineralization of nitrogen and phosphorus, could have contributed also to the lowering of the pH.

TABLE 2

Effect of different soil faunal treatments on nutrient availability and pH in the soil, and quantities of nutrient elements absorbed by black spruce needles

Treatment symbol	Soil					pH
	p.p.m.		me/100 gm			
	N	P	K	Ca	Mg	
A	59	61	0.52	3.73	1.27	4.4
B	113	111	0.41	4.92	1.31	4.0
C	96	58	0.62	3.63	1.17	4.6
D	27	72	0.44	4.00	1.36	4.8
	Needles (p. 100)					
	N	P	K	Ca	Mg	
A	2.29	0.27	0.50	1.20	0.20	—
B	2.31	0.23	0.47	1.20	0.20	—
C	2.31	0.27	0.50	1.14	0.21	—
D	2.22	0.22	0.43	1.30	0.20	—

Population Changes

Table 3 shows qualitative and quantitative changes that occurred in the soil fauna during the experiment. Figures obtained for field populations in October, when they were expected to be at their maxima, are also given for comparison. The numbers in the different taxonomic groups from the greenhouse were very similar and were in close agreement with figures from the field. The range for total arthropods of 1 770 to 2 445 is common in field populations (MURPHY, 1955, 1962 ; BERTHET and GERARD, 1965 ; HALE, 1966) because of the aggregated distribution of most soil animals. The exceptionally large figure in the defaunated treatment was due to the massive occurrence of a *Liochthonius* nymph, which accounted for over 75 p. 100 of the Cryptostigmata. Evidently some of the specimens survived the drying treatment or must have migrated to the defaunated soil during the course of the experiment. In the absence of competition and low predation by Mesostigmata, the *Liochthonius* species multiplied rapidly.

The total number of species of arthropods are similarly uniform for the four treatments, but the 33 species in treatment C, the largest number surviving in the greenhouse, is only slightly more than half the 56 species found in the field. Apart

TABLE 3

Changes in the soil animal population during the experiment. Figures for arthropods are averages of three samples and expressed as numbers per 100 grams of oven dry soil (110°C). *Earthworms are totals from each treatment.* A. caliginosa *and* L. terrestris *in* (B) *are from inoculation.*

	Number in the field at start of experiment		Number at end of experiment in the greenhouse							
			Species				Individuals			
	Species	Individuals	A	B	C	D	A	B	C	D
Arthropoda :										
Mesostigmata	6	83	6	4	6	1	235	187	219	129
Prostigmata	12	364	2	2	2	5	100	97	28	84
Astigmata	3	14	1	2	1	1	6	53	7	4
Cryptostigmata	21	1 504	12	14	14	12	1 261	1 398	1 005	1 972
Total *Acarina*	42	1 965	21	22	22	19	1 602	1 735	1 259	2 189
Collembola	9	145	6	5	7	8	241	209	429	245
Others	5	14	5	2	4	3	50	47	82	11
Total Arthropods	56	2 124	32	29	33	30	1 893	1 991	1 770	2 445
Lumbricidae :										
D. octaedra	1	?	1	1	1	1	114	86	90	17
A. caliginosa	0	0	1	1	0	0	1	27	0	0
L. terrestris	0	0	0	1	0	0	0	9	0	0

from the defaunated treatment, where the common mesostigmatid mite *Parazercon radiatus* BERLESE was missing, the Prostigmata and Cryptostigmata sustained the heaviest losses. Among the genera found in the field but not extracted at the end of the experiment were *Leptus*, *Lordalychus*, *Nanorchestes*, and *Scutacarus* in the *Prostigmata* and *Archoplophora* and *Palaeacarus* in the *Cryptostigmata*.

The small earthworm *Dendrobaena octaedra* (SAVIGNY), occurred naturally in the field but its density was not determined. At the end of the experiment about five specimens per pot were recovered from treatments A, B and C. Seventeen specimens were also collected in five pots from treatment D. Of the inoculated species, 34 p. 100 and 23 p. 100 of *A. caliginosa* and *L. terrestris* survived, respectively. The single specimen of *A. caliginosa* collected from treatment A indicates that some specimens might have escaped from the pots that were inoculated. Others undoubtedly perished as a result of over exposure to formalin or adverse conditions in the acid spruce soil. Low survival of *L. terrestris* when introduced to uncolonized soils has been recorded also by RHEE (1969 *a*).

DISCUSSION

The data presented here suggests that some differences in plant growth may be due to soil faunal activity ; and these differences are probably related to the levels of plant nutrients, especially nitrogen and phosphorus, in the soil.

Little is known about the direct effects of the saprophagous soil fauna on tree growth. The mineralization of nitrogen, which is perhaps the most important limiting nutrient in most soils, is greatly increased by earthworm activity (BARLEY and JENNINGS, 1959 ; PARLE, 1963 ; SATCHELL, 1967). The resulting effect on plants have been variable for the species investigated, but there has been generally an increase in yield. ZRAZHEVSKĬ (1958) found a 26 p. 100 and 37 p. 100 increase in the weight of two-year-old seedlings of pedunculate oak (*Quercus robur* L.) and green ash (*Fraxinus pennsylvanica* MARSH.), respectively, for pots with live earthworms and controls. In my results, the observed increase in available nitrogen and phosphorus accompanied by a 17 p. 100 increase in top weight for the live earthworm treatment indicates that the beneficial influence resulted from increased available nutrients from the decomposing litter. This increase could not have resulted only from the manuring effects of dead worms (cf. HOPP and SLATER, 1949 ; SATCHELL 1958) because at least 30 p. 100 of the specimens survived.

The increased plant vigor in treatment D is difficult to interpret as a combination of factors might be involved. It is possible that the low top : root ratio resulted from a physiological reaction of the plant to low nitrogen supply in the soil (BURSTRÖM, 1965) and not to the direct activities of soil animals. An alternative hypothesis is that the drying treatment controlled plant parasitic nematodes and unknown plant inhibitors, or initiated a beneficial ecosystem shift in the plant rhizosphere favouring plant sustainers (KREUTZER, 1965).

The slight increase in yield of the defaunated treatment is expected to be short-lived as nitrogen deficiency would eventually limit plant growth. Therefore the maintenance of a high level of faunal activity in the soil is of great practical importance to forestry. Some forest soils immobilize vast quantities of nitrogen in organic matter

that decomposes slowly (WEETMAN, 1962). For such soils, silvicultural practices that enhance natural or introduced saprophagous fauna should result in increased forest productivity.

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RÉSUMÉ

EFFETS DES ARTHROPODES DU SOL ET DES VERS DE TERRE SUR LA CROISSANCE DE L'ÉPICÉA NOIR

Dans un essai expérimental casualisé, nous avons étudié l'influence de la faune du sol sur la croissance de l'épicéa noir (*Picea mariana* (MILL.) BSP.) en serre chaude. Quatre-vingts pots, contenant chacun une jeune plante dans du sol forestier naturel, ont été soumis aux quatre traitements suivants : (A) le témoin : sol avec sa faune naturelle ; (B) sol avec sa faune naturelle et inoculé avec des spécimens vivants d'*Allolobophora caliginosa* (SAVIGNY) et *Lumbricus terrestris* L. à la densité de 9.0 g par kg de sol ; (C) sol avec sa faune naturelle et inoculé avec des lumbrics morts à la densité de 8.8 g par kg de sol et (D) sol dont la faune a été tuée par dessiccation.

Les résultats n'ont donné des différences significatives (par le test du « F », avec une probabilité de 10 p. 100) que pour le traitement comportant des vers vivants (B) ; mais les autres données sont intéressantes, surtout pour les parties aériennes des plantes. Le traitement (B) a produit beaucoup plus d'azote et de phosphore échangeables ; il a aussi déterminé un accroissement en poids (des parties aériennes) qui a été de 17 p. 100 supérieur à celui du témoin. Dans les pots sans faune (D) et dans ceux qui ont été additionnés de cadavres de vers (C), la production a été de 8 p. 100 supérieure à celle du témoin.

En ce qui concerne le poids total des plantes, l'accroissement maximal a été obtenu dans les pots sans faune, mais le rapport entre poids des parties aériennes et poids des racines, dans ces pots, a été le plus faible des quatre traitements. Le taux réduit d'azote minéralisé dans le sol indique que cette productivité exceptionnelle doit être éphémère. L'auteur conclut que la destruction des animaux terricoles de la forêt provoquerait une diminution sérieuse de la fertilité des sols et, par conséquent, de la productivité des plantes.

REFERENCES

ATKINSON H. J., GILES G. R., MAC LEAN A. J., WRIGHT J. R., 1958. Chemical methods of soil analysis. *Can. Dept. Agric. Contr.* N° 169 (Rev. Chem. Div., Sci. Service) 90 p.

ATLAVINYTÉ O., BAGDONAVIČIENÉ Z., BUDAVIČIENÉ I., 1968. The effect of Lumbricidae on the barley crops in various soils. *Pedobiologia*, **8**, 415-423.

BACHELIER G., 1963. *La Vie Animale dans les Sols*. O. R. S. T. O. M., Paris, 279 p.

BARLEY K. P., 1961. The abundance of earthworms in agricultural land and their possible significance in agriculture. *Adv. Agron.*, **13**, 249-268.

BARLEY K. P., JENNINGS A. C., 1959. Earthworms and soil fertility. III. The influence of earthworms on the availability of nitrogen. *Aust. J. agric. Res.*, **10**, 364-370.

BARRETT T. J., 1949. *Harnessing the Earthworm*. Faber and Faber Ltd., London. xvi + 166 p.

BERTHET P., GERARD G., 1965. A statistical study of microdistribution of Oribatei (Acari). Part I. The distribution pattern. *Oikos*, **16**, 214-227.

BLACK C. A. (Ed.), 1965. Methods of soil analysis. Part 2 : Chemical and Microbiological Properties. *Am. Soc. Agron., Inc.*, Madison : xlii, 771-1572, lxii p.

BOCOCK K. L., 1964. Changes in the amounts of dry matter, nitrogen, carbon and energy in decomposing woodland leaf litter in relation to the activities of the soil fauna. *J. Ecol.*, **572**, 273-284.

BURSTRÖM H. G., 1965. The physiology of plant roots. *In* Baker, K. F. and Snyder, W. C. (Ed.). *Ecology of Soil-Borne Plant Pathogens. Prelude to Biological Control.* Univ. Calif. Press, Berkeley, 154-169.

DAVID D. J., 1960. The determination of exchangeable sodium, potassium, calcium and magnesium in soils by atomic-absorption spectrophotometry. *Analyst,* Lond. **85**, 495-503.

DUFF H. A., 1958. Pasture improvement in low altitude tussock and scrub-land. *N. Z. Grassld. Ass. Proc.* **20**, 70-79.

FRASER D. A., 1958. The relation of environmental factors to flowering in spruce. *In* Thimann, K. V. (Ed.). *The Physiology of Forest Trees.* The Ronald Press Co., New York, 629-642.

GERARD B. M., 1963. The activities of some species of lumbricidae in pasture-land. *In* Doeksen, J. and Drift, J., Van der (Ed.). *Soil Organisms.* North-Holland Publishing Co., Amsterdam, 49-54.

HALE W. G., 1966. A population study of moorland Collembola. *Pedobiologia,* **6**, 65-99.

HOPP H., SLATER C. S., 1949. The effect of earthworms on the productivity of agricultural soil. *J. agric. Res.,* **78**, 325-339.

KEVAN D. K. McE., 1968. Soil fauna and humus formation. *Trans. 9th Int. Congr. Soil Sci.,* **2**, 1-10.

KREUTZER W. A., 1965. The reinfestation of treated soil. *In* Baker, K. F. and Snyder, W. C. (Ed.). *Ecology of Soil-Borne Plant Pathogens. Prelude to Biological Control.* Univ. Calif. Press, Berkeley, 495-508.

LANGMAID K. K., 1964. Some effects of earthworm invasion in virgin podzols. *Can. J. Soil Sci.,* **44**, 34-37.

MACFADYEN A., 1968. The animal habitat of soil bacteria. *In* Gray, T. R. G. and Parkinson, D. (Ed.). *The Ecology of Soil Bacteria.* Liverpool University Press, Liverpool, 66-76.

MARSHALL V. G. Efficiency tests for soil-mite extractors, with special reference to funnel processes. *Advances in Acarology.* **3** (in press).

METZ L. J., FARRIER M. H., 1965. Forest soil fauna and the forest floor. *In* Youngberg, C. T. (Ed.). *Forest-Soil Relationships in North America.* Oregon State University Press, Corvallis, 25-31.

MURPHY P. W., 1955. Ecology of the fauna of forest soils. *In* Kevan, D. K. McE. (Ed.). *Soil Zoology.* Butterworths, London, 99-124.

MURPHY P. W., 1962. Effect of sample treatment on extraction efficiency with the split funnel extractor. *In* Murphy, P. W. (Ed.). *Progress in Soil Zoology.* Butterworths, London, 182-188.

PARLE J. N., 1963. A microbiological study of earthworm casts. *J. gen. Microbiol.,* **31**, 13-22.

RAW F., 1959. Estimating earthworm populations by using formalin. *Nature,* Lond. **184**, 1661-1662.

RHEE J. A. van, 1965. Earthworm activity and plant growth in artificial cultures. *Pl. Soil,* **22**, 45-48 + 2 pl.

RHEE J. A. van, 1969. *a*. Development of earthworm populations in polder soils. *Pedobiologia,* **9**, 133-140.

RHEE J. A., van, 1969 *b*. Inoculation of earthworms in a newly drained polder. *Pedobiologia,* **9**, 128-132.

RODALE R. (Ed.)., 1961. *The Challenge of Earthworm Research.* The Soil and Health Foundation, Emmaüs., 102 p.

ROOTS B. I., 1956. Famous animals. -7. The earthworm. *New Biology,* **21**, 102-117.

SATCHELL J. E., 1958. Earthworm biology and soil fertility. *Soils Fertil.,* **21**, 209-219.

SATCHELL J. E., 1967. *Lumbricidae. In* BURGES, A. and RAW, F. (Ed.). *Soil Biology.* Academic Press London, 259-322.

WEETMAN G. F., 1962. Nitrogen relations in a black spruce (*Picea mariana* MILL.) stand subject to various fertilizer and soil treatments. *Pulp Pap. Res. Inst. Can., Wood. Res. Index* n° 129, viii + 112 p.

WITKAMP M., CROSSLEY D. A. Jr., 1966. The role of arthropods and microflora in breakdown of white oak litter. *Pedobiologia,* **6**, 293-303.

ZRAZHEVSKI A. I., 1958. Earthworms and the interrelations of tree and shrub species. *Priroda Mosk.,* **47**, 96-08 (in Russian).